The Argo Project
Global Ocean Observations for Understanding and Prediction of Climate Variability

Report for Calendar Year 2004

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Award Numbers: *(NA17RJ1231 (SIO), NA17RJ1223 (WHOI), N00014-01-1-1064 (UW))*

LONG-TERM GOALS

The U.S. component of the international Argo Project (http://www.argo.ucsd.edu) is implemented through this award. The present report covers Year 3 of the 5-year project, and builds on progress made by previous awards (Phases 1 and 2) for pilot float arrays and data system development.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2004		**00-00-2004 to 00-00-2004**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
The ARGO Project Global Ocean Observations for Understanding and Prediction of Climate Variability	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Scripps Institution of Oceanography,La Jolla,CA,92093-0230**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
A National Oceanographic Partnership Program Award.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**10**	

By the end of 2006, Argo will have deployed a global array of 3000 profiling CTD floats (Roemmich and Owens, 2000, Roemmich et al, 2002, Gould, 2004), and established a data system to meet the needs of both operational and scientific users for data delivery in real time and delayed mode. The Argo array will provide unprecedented views of the evolving physical state of the ocean. It will reveal the physical processes that balance the large-scale heat and freshwater budgets of the ocean and will provide a crucial dataset for initialization of and assimilation in seasonal-to-decadal forecast models. Argo is a major initiative in oceanography, with research and operational objectives, providing a global dataset for climate science and other applications. It is a pilot project of the Global Ocean Observing System.

OBJECTIVES

Phase 1 (9/99 – 9/02) and Phase 2 (7/00 – 6/02) of US Argo provided a total of 187 CTD profiling floats in the Pacific, Atlantic and Indian Oceans. Objectives were to demonstrate technological capabilities for fabrication and for deployment of float arrays in remote ocean locations (Phase 1) and to demonstrate the capability for manufacture and deployment of large float arrays (Phase 2). Recent technology developments in profiling floats were also implemented, including new generation salinity sensors, improved depth capability, and deployment techniques using fast ships and aircraft. Development of the U.S. Argo Data System was part of Phase 1, on a collaborative basis with international partners. Objectives are to make all Argo data publicly available within a day of collection, applying automated quality control procedures consistent with international Argo practices. Data appropriate for research applications and for comparison with climate change models are not available for several months since they need quality control by salinity experts and evaluation of data over many (10 day) float cycles. Phase 3 is a 5-year project (8/01 – 6/06) including full implementation of the US component of Argo. This report includes Phase 3/Year 3, which deployed 390 CTD profiling floats during CY2004 plus support for these deployments, data management activities and for national and international coordination of Argo. Float deployments targeted the Atlantic, Pacific, Indian, and Southern Oceans. Priorities for US float deployment are set by the US Argo Advisory Panel.

APPROACH AND WORK PLAN

Float production and float deployment has been accomplished by four facilities – SIO (D. Roemmich and R. Davis - float production and deployment), WHOI (W.B. Owens – float production)/AOML (S. Garzoli – float deployment), UW (S. Riser – preparation and deployment of commercially manufactured floats), and PMEL (G. Johnson – deployment of commercially manufactured floats. This distributed effort has been designed to safeguard the US contribution to the Argo project from unforeseen problems at any one component institution. It also makes Argo success independent of the participation of any individual PI and institution or of any single float design. It allows the large amount of effort to be shared. It encourages individual technical innovation and enhancement. While the initial focus has needed to be on improving float performance, attention of the PIs will increasingly focus on exploiting the scientific value of Argo. The data system is

also distributed, but by function rather than for load-sharing. AOML (R Molinari) is the national Argo data center, responsible for acquiring the float data received by satellite communications, for carrying out real-time quality control, and for distribution of data via the GTS and to the Global Argo Data Assembly Centers. The second step in data management is a semi-automated recalibration of the salinity sensor carried out by PMEL (G. Johnson), using a high quality temperature/salinity climatology for comparison with float temperature/salinity data (Wong et al, 2003). The final step is individual examination of all profiles by the float-providing PIs, in order to provide high-quality data suitable for research applications. US Argo PIs are involved in all of these components.

All Argo data are freely available within about 24 hours of collection, and can be accessed from the GTS or internet (http://www.usgodae.org/, or http://www.ifremer.fr/coriolis/cdc/argo.htm).

WORK COMPLETED

It was reported in 2002 that, based on the performance of the pilot arrays deployed in Phases 1 and 2, design and production problems were detected in both SOLO and APEX floats that led to shortened instrument lifetimes. Extensive technical analysis and redesign was carried out over the first 9 months of 2002, leading to substantial improvements in float pumping and control subsystems. Large-scale float deployments were resumed in the 4th quarter, and by year's end about 1/3 of the Phase 3/Year 1 floats were deployed. Deployment of these modified designs have continued with promising results. Over the first year of operation the failure rates are about 20% lower than with the older designs.

Deployment of the remaining Year 1 instruments plus most Year 2 instruments was completed in 2003 – a total of 290 deployments. A significant disruption was caused by a recall of salinity sensors by SBE in August 2003. A problem associated with the pressure sensor had been detected by S. Riser at UW. Riser worked with the manufacturer to identify the fault. This resulted in the recall and a hiatus in the deployment of floats with SBE sensors that effectively lasted to the end of 2003.

There is enough data on the redesigned floats to confirm that significant improvements have occurred in float lifetimes, much of that due to the technical and engineering efforts of the U.S. partners. Figure 1 is a composite of the failure rates of all of the floats in the international program. In 2001 and 2003 and the U.S. floats only in 2003 and 2004. The Argo program plan has a goal of a 10% failure rate over four years (146 cycles). Floats deployed in 2004 have not been deployed for a large number of cycles but these early results indicate that the U.S. float reliability has improved as a result of these technical improvements and may be approaching the goal of 10% failures over four years.

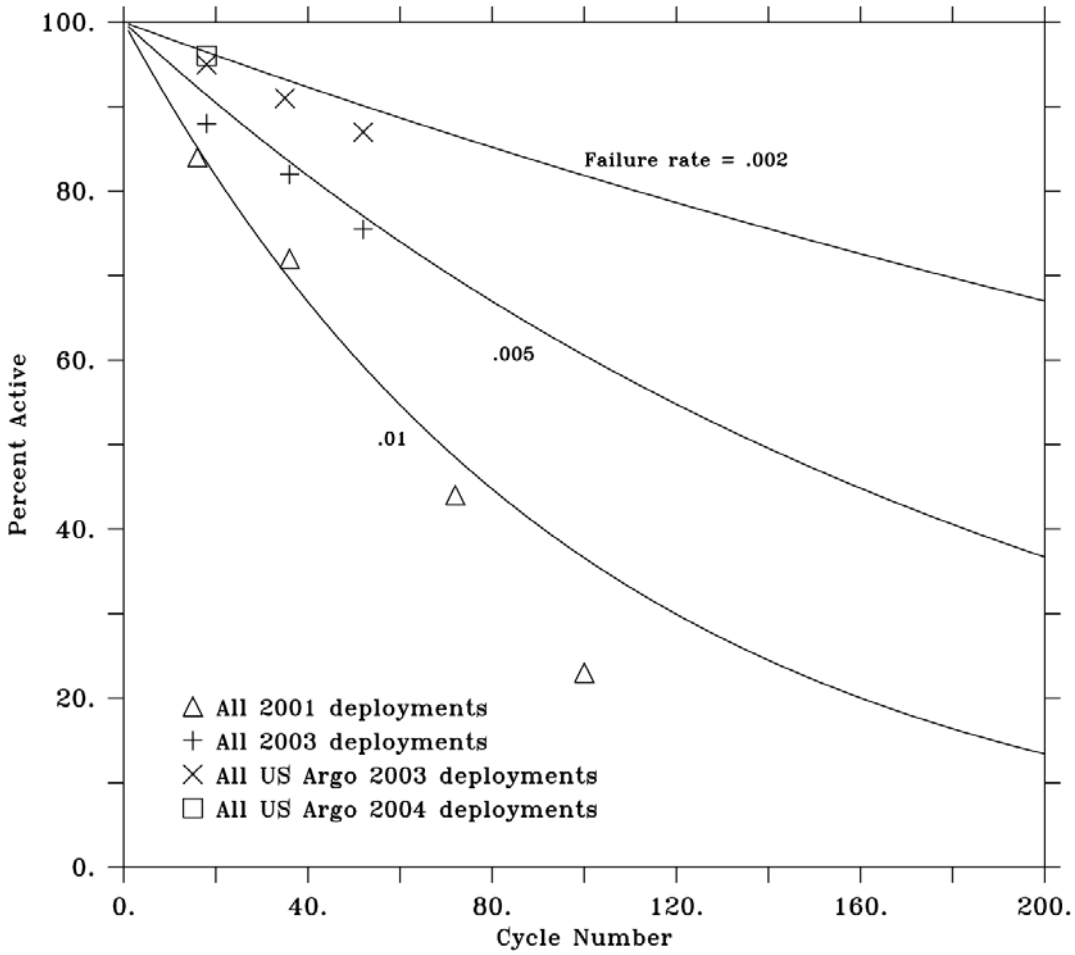


Figure 1: *Float Reliability*

All Argo profiles are now subjected to the internationally-agreed automated quality control procedures and are distributed via the GTS. The US Argo Data Center (AOML) provides all US data to the Global Argo Data Assembly Centers (GDACs) in Monterey, California and Brest, France in standardized Argo NetCDF format. The US delayed-mode data center (PMEL) provides suggested salinity recalibration information for US floats and has led the development of procedures that were endorsed by the Argo Science Team in March 2003 for incorporating delayed-mode quality control in the standard data files. After PI examination, the delayed-mode salinity data will be distributed by the U.S. Argo Data Center.

The US GDAC serves the global collection of Argo profiles through OPeNDAP servers, and Live Access Server from NOAA/PMEL. These servers integrate Argo data into the National Virtual Ocean Data System (NVODS), and the International Ocean Observing System Data Management and Communications (IOOS/DMAC) scheme.

The U.S. Program plays a strong role on the international Argo Data Management Team. Mark Ignaszewski (FNMOC) is now ADT co-chair. The PMEL technique for salinity recalibration has been distributed to international partners, along with assistance in getting it running, and it has been adopted internationally. AOML, participating on the ADMT, provides input to methodology development and leads efforts in product evolution. Finally, in the data management realm, AOML has provided assistance to other groups (e.g., China, South Korea and India) as they establish their real-time data management procedures.

Data management methodology is not static. Both AOML and PMEL continue to implement changes in the procedures required by the international Argo Data Management Team.

The US is the technology leader in profiling floats, and our technical improvements have been shared with international partners. 85% of all of the present Argo array is made up of floats manufactured in the USA.

The consortium plays strong leadership roles in the international Argo project. In the past year this support has included the employment of Dr. John Gould as Argo Director, located at Scripps Institution of Oceanography alongside Dr. Dean Roemmich (Argo Science Team Chairman). US consortium members provide coordination for deployment planning in the Pacific, Atlantic, and Southern Oceans.

RESULTS

The international Argo array now includes 1572 floats (Figure 2, from http://argo.jcommops.org) compared with 1045 active floats a year earlier. This represents slightly more than one-half of the 3000 float array planned for completion by the end of 2006. Float deployments increased steeply in the past year, especially in the remote sparsely sampled regions. Much of this was due to collaborations with the National Institute of Water and Atmospheric Research in New Zealand using the research vessel KAHAROA. AOML partnerships with Brazil, Argentina and South Africa will provide deployment opportunities in the South Atlantic Ocean in 2005 and the links with NIWA will continue enabling continued coverage of the remote and logistically difficult South Pacific.

The northern hemisphere bias of the array is diminishing (53% in NH). Data are being used by at least 12 operational centers worldwide, and by a broad community of researchers. The Argo Data Management System is operating, delivering profiles in near real-time to operational and other users via the GTS and the internet. The ability to produce scientific-quality data has been demonstrated and is starting to be implemented for all floats with public internet distribution.

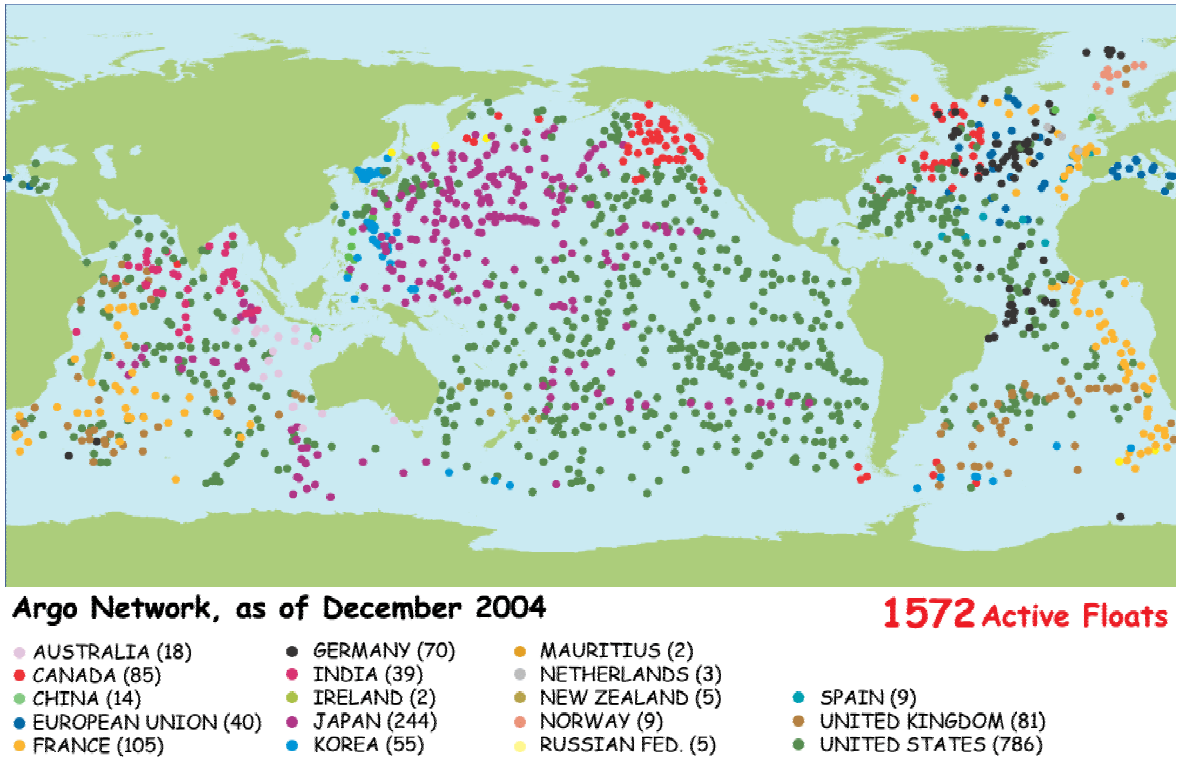
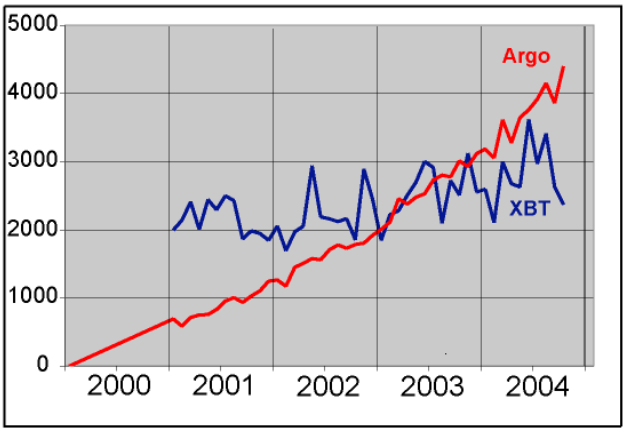


Figure 2: *The Argo Array as of 31 December 2004 (786 US floats in Red)*

Although the Argo Project is still young it has made possible a wide range of operational and research applications of Argo and pre-Argo profiling float data. This was clearly demonstrated at the First Argo Science Workshop held in Tokyo in November 2003 and co-sponsored by NOAA. There were 85 oral and poster presentations on topics ranging from the air-sea interaction below tropical cyclones, monsoonal and ENSO effects, seasonal mode water production, investigation of basin-scale ocean currents, global ocean heat and fresh water storage and the detection and attribution of climate change. These presentations can be accessed at http://www.argo.ucsd.edu/. US PIs are conducting research in all of these areas and there is increasing use of Argo data in operational centers. The PI-led research is reflected in the attached bibliography.

It is clear that Argo's contributions to the ocean observing system – including observations of subsurface salinity and extensive coverage of remote ocean areas – are a profound increment in our ability to characterize water masses and large-scale circulation, (Figure 3) and to make accurate estimates of heat and freshwater storage and their transport by ocean currents..

A



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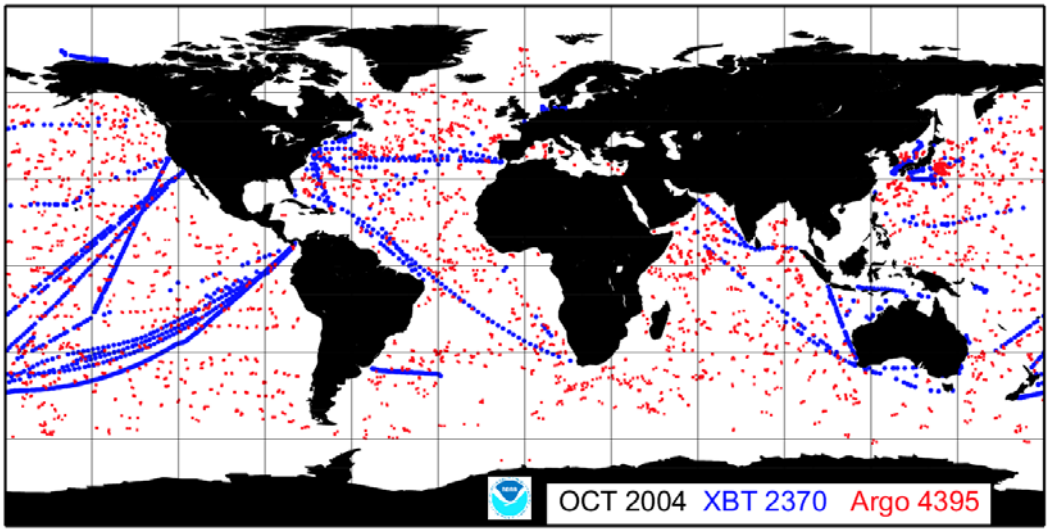

Figure 3: (A) *Argo and XBT Near Real-Time Profiles Per Month;* **(B)** *Data Delivered in Real Time during October 2004 from Argo (4395 Profiles Typically to Over 1000m - Red Dots) and from the High density XBT Network (Temperature Only to Typically 750m – Blue Dots). Courtesy AOML.*

The quasi-random distribution of Argo data compared with data provided by ships is demonstrated in Figure 2B. Argo's uniform distribution provides the ideal complement to satellite altimetry data (Willis et al, 2003) so as to address the issues of global heat and fresh water storage and sea level rise and for data assimilation into global models.

IMPACTS, APPLICATIONS, AND TRANSITIONS

National Security

The US Navy has a strong interest in accurate estimates and forecasts of the physical state of the ocean and the coupled air-sea system, because of the obvious impacts of

wind, waves, currents, and temperature on virtually all aspects of naval operations. The Navy has experimental ocean state estimation and forecasting efforts, using both regional and global models, for which Argo provides a central contribution for ocean data assimilation. The Navy interest is further expressed by the hosting of one of the two Global Argo Data Centers (at FNMOC, Monterey), by NAVOCEANO participation as a provider of floats for international Argo, and by NAVOCEANO participation in air deployment of Argo floats. Phase 1 of US Argo was supported by ONR.

Economic Development

The Global Ocean Data Assimilation Experiment (GODAE) has identified a number of applications with substantial economic impacts arising from ocean observations, including improved seasonal-to-interannual (S-I) forecasting, state estimation (now-casting), and coupled physical/biological modeling (e.g., for fisheries). The El Niño/Southern Oscillation (ENSO) Observing System in the tropical Pacific has demonstrated over the past decade that economic gains in energy, agriculture, and insurance sectors are possible from successful seasonal forecasts. Improvement in S-I forecasting is expected as the tropical observing system is extended and expanded to global coverage, and Argo plays a key role in that expansion.

Quality of Life

Argo is central to an unprecedented capability for global assessment of the evolving climate state of the ocean. The thermal structure of the upper ocean controls the temperature of the lower atmosphere, and is the primary variable defining the physical environment of ocean ecosystems. Over 90% of the increased heat content due to global warming of the air/sea/ice climate system in the past 40 years occurred in the oceans. Climate stresses on ocean ecosystems have serious consequences, and sometimes dramatic ones, such as coral reef bleaching. In the future, the impacts of a varying climate on the health of the seas and coastal ecosystems will become an increasingly important aspect of resource management. The unique niche of the Argo array is to provide global broadscale observations of the upper ocean.

Science Education

Although the Argo project is still very new, it is proving to be an attractive educational asset for secondary, tertiary, and post-graduate levels. For secondary education, the web-based and real-time nature of the Argo data system, as well as Argo's strong climate-relevance, have been keys to engaging student interest in the oceans. Our consortium participates in a UNESCO and IOC-sponsored initiative called SEREAD, (http://argo.jcommops.org/), that uses Argo data in existing secondary science curricula in Pacific Island countries. In post-graduate education, Argo is already providing primary data for dissertation research of graduate students in the U.S. and other countries.

RELATED PROJECTS

GODAE: The Global Ocean Data Assimilation Experiment uses satellite and in situ ocean datasets in data assimilation models for practical applications. Argo plays a special role in GODAE because it is the only globally repeating subsurface ocean dataset, and is strongly complementary to its satellite counterparts. GODAE's vision is "A global system of observations, communications, modeling and assimilation, that will deliver regular, comprehensive information on the state of the oceans, in a way that will promote and engender wide utility and availability of this resource for maximum benefit to the community" (http://www.bom.gov.au/bmrc/ocean/GODAE/).

CLIVAR: (Climate Variability and Predictability experiment of the World Climate Research Program). Argo provides a primary ocean dataset for this experiment targeting better understanding of the climate system, including its variability and predictability. (See http://www.clivar.org.) CLIVAR's aim is to exploit the research value of broadscale climate observations and focused process experiments. In this context, Argo measures the storage and transport of heat and freshwater globally on broad spatial scales.

Global CO_2 Flux Map Project: Argo provides near surface salinity and temperature to the NOAA Office of Global Programs funded project directed at providing global maps of CO_2 surface fluxes. The float data will be used in algorithms (developed from pCO_2 observations) that provide estimates of surface carbon fluxes from surface salinity and temperature data.

US Argo Consortium RELEVANT WEB SITES:
Argo Science Team home page http://www-argo.ucsd.edu,
Argo Information Center http://argo.jcommops.org,
Scripps Institution of Oceanography http://sio-argo.ucsd.edu,
Woods Hole Oceanographic Institution http://ursa.whoi.edu/~argo/,
University of Washington http://flux.ocean.washington.edu/argo/,
NOAA PMEL http://floats.pmel.noaa.gov/argo,
NOAA PMEL(Delayed Mode QC)) http://www.aoml.noaa.gov/phod/ARGO/HomePage/,
NOAA PMEL (General) http://floats.pmel.noaa.gov/floats
US GDAC http://www.usgodae.org

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